NASA CR- 139046

TRACKING AND DATA RELAY
SATELLITE NETWORK CONFIGURATION STUDY

# TECHNIQUES FOR ANALYZING AND UTILIZING THE RAIN GAUGES AT THE NASA WHITE SANDS TEST FACILITY

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MAY 1973
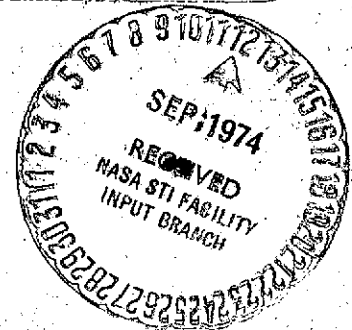
THE MITRE

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## ABSTRACT

Ten tipping bucket rain gauges have been installed at the NASA
WSTF for the purpose of determining rainfall characteristics in this
area which may affect the performance of the NASA Tracking and Data
Relay Satellite System (TDRSS). This paper presents a plan for anal-
yzing and utilizing the data which will be obtained during the course
of this experiment. Also included is a description of a computer pro-
gram which has been written to aid in the analysis.

CONTRACTUAL

This report is submitted as part of the Final Report of work completed under NASA GSFC Contract Number NAS 5-20331.

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## 1.0  INTRODUCTION

During late April and early May, ten tipping bucket rain gauges and event recorders were installed at the NASA White Sands Test Facility for the purpose of gathering detailed rainfall data at one of the potential Tracking and Data Relay Satellite (TDRS) Ground Station locations. A description and data collection plan for this experiment was published previously in a MITRE Working Paper and is reproduced in Appendix I of this document. The remainder of this report presents a plan for utilizing the data which will be collected during the course of the experiment. Since no data became available during the course of MITRE's contract with NASA, there are no actual results to be reported.

Section 2.0 presents a brief description of the equipment which is installed at the WSTF. The format of the chart recordings from the rain gauges and instructions for converting this recorded raw data to rainfall rate data are given in Section 3.0. Also given in Section 3.0 is a description of a computer program which will reduce the rain gauge raw data and display it in tables in the form of rainfall rate, attenuation, and total accumulation. The program is listed in Appendix II. Finally, Section 4.0 presents suggested techniques for further processing of the data to determine antenna site diversity improvement, characteristics of storms, correlation with the radiometer at WSTF and optimum operational procedures.

## 2.0 DATA COLLECTION EQUIPMENT

This section discusses the rain gauge and chart recorders that were selected for use at WSTF. A brief sketch of how this equipment operates is necessary in order to understand the techniques that will be used to process the raw data obtained from the rain gauges.

### 2.1 Tipping Bucket Rain Gauge

The rain gauge which was acquired for use in this experiment is the P501-1 Remote Recording Rain Gauge manufactured by Weather Measure Corporation of Sacramento, California. The gauge consists of a small bucket which collects rain as it falls. When 0.01 inches of rain is collected, the bucket tips emptying the rain accumulation and momentarily closing a mercury switch. The advantage of this type of gauge is that rainfall accumulation can be measured without the need to read the gauge and empty it after each rainfall. Also, rainfall rate can be determined by recording the elapsed time between tips of the bucket. Rainfall rates in excess of 10 inches per hour can be resolved with this tipping bucket gauge.

### 2.2 Long Term Event Recorder

The mercury switch on the rain gauge, which is closed for each tip of the rain bucket, is used to activate a solenoid on a P522 long term event recorder made by the same manufacturer as the rain gauge. The recorder normally has a chart speed of 1/4 inch per hour but has been modified by the manufacturer to a speed of 2 inches per hour. Since the primary interest in this experiment is the determination of rainfall rate, this high chart speed was necessary in order to read, with any reasonable degree of detail, the time between tips of the bucket. An even higher speed would be desirable, but would cause the chart to need replacement more often than the 12 day interval now necessary and thus a chart speed of 2 inches per hour is somewhat of a compromise.

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## 3.0 PROCESSING OF RAW DATA

This section describes the format of the raw data, explains how to convert these data to rainfall rates, and describes a computer program which has been written to accomplish this conversion and print out tables that can be used to analyze the data.

### 3.1 Format of Chart Recordings

The paper on the chart recorder that is used with the rain gauge is a 49 foot roll, two inches wide. The recorder has been modified for this project so that the chart speed is two inches per hour. The chart, a sample of which is shown in Figure 1, has a division every one-eighth inch corresponding to an elapsed time of 3.75 minutes. An event (i.e., a tip of the rain gauge bucket) is recorded by a vertical movement of the pen across the width of the chart. There are twenty-five divisions across this two-inch chart and each event moves the pen by one-half division. Therefore, fifty events are recorded by a two-inch movement of the pen across the chart.
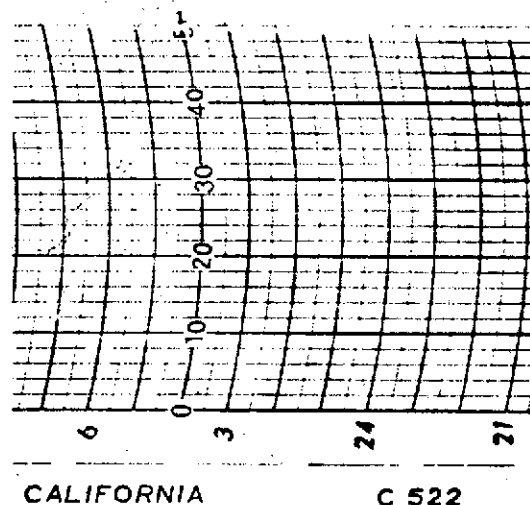
FIGURE 1

EXAMPLE OF STRIP CHART

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## 3.2 Conversion to Rain Rate

The conversion of the raw data on the chart recorder to rainfall rate is accomplished by noting that for every 0.01 inch of rain which is collected by the rain gauge, the pen moves by one-half division on the vertical scale of the chart. By measuring the time in hours between two such movements of the pen and dividing 0.01 by this time, the rainfall rate in inches per hour is determined. Unfortunately, the speed of the chart is so slow that it would be rather difficult to accurately measure the time between events as well as the absolute time of each event. Thus the procedure described below is recommended and should simplify the data reduction and processing although some accuracy may be sacrificed at the very low rain rates. Since these low rain rates are not really of interest, there should be no major problems.

The technique suggested for use is as follows. In the horizontal or time direction, the chart is divided into one-eighth inch increments corresponding to an elapsed time of 3.75 minutes. By counting the number of events (i.e., tips of the rain gauge bucket) within each division, multiplying by 0.01 inches of rainfall and dividing by .0625 hours (3.75 minutes) the average rainfall rate in inches per hour for that period of time will be determined. If this same procedure is followed for each of the ten rain gauges, then the time period can be easily correlated between the rain gauges by just recording the initial time at which data is taken. It is also necessary that the chart be properly marked when the paper is changed. Appendix I contains all of the details on field servicing the recorders.

## 3.3 Computer Program

A computer program has been written that will accomplish the above procedure. This program is listed in Appendix II and contains numerous

comments and detailed instructions for preparing the data cards. Since at the time this report was written, there were no data available from the rain gauges, a set of dummy data was prepared in order to test the program. Table I shows a listing of the results of running the program with this dummy data. Notice that all of the data starts at the earliest time that rain was recorded at any of the ten gauges and continues until the rain ends at the last gauge. Even if some gauges did not receive rain, they are still shown with all of the rain rates shown as zero. By scanning across the page at a common time, a quick idea can be had as to how the rain rate varies over the area in which the rain gauges are set up in.

The same data is also presented in another form in Table II. In this table, all of the rain rates have been converted to the attenuation that a 15.3 GHz signal would experience on a 9.35 km path through a rainfall with a constant rate given by the value in Table I. The 9.35 km path length corresponds to an earth-to-satellite path with a 20 degree elevation angle, assuming a storm height of 3.2 km. Notice that the format is the same for both tables with just the entries differing.

Finally, the amount of rainfall that was recorded at each gauge is calculated and printed. An example from the dummy data is shown in Table III. This table can quickly illuminate factors such as storm movement. For example, if two gauges receive the same amount of rainfall but have vastly different rainfall rates, then it is likely that the storm was moving parallel to the line connecting the gauges.

This program can form the basis for a quick look at each storm and can be expanded later when some actual data are available.

## TABLE I
## EXAMPLE OF PROGRAM OUTPUT IN RAINFALL RATE

RESULTS FOR STORM ON APRIL 1 1973

RAINFALL RATE IN INCHES PER HOUR

| TIME | GAUGE NO 1 | GAUGE NO 2 | GAUGE NO 3 | GAUGE NO 4 | GAUGE NO 5 | GAUGE NO 6 | GAUGE NO 7 | GAUGE NO 8 | GAUGE NO 9 | GAUGE NO 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2133.750 | 0.1600 | 0.3200 | 0.0000 | 1.9200 | 0.0000 | 1.1200 | 1.1200 | 0.0000 | 4.3200 | 0.4800 |
| 2137.500 | 0.4800 | 0.4800 | 0.0000 | 2.0800 | 0.0000 | 0.4800 | 0.4800 | 0.0000 | 0.4800 | 0.6400 |
| 2141.250 | 1.1200 | 0.6400 | 0.0000 | 0.0000 | 0.0000 | 1.9200 | 0.6400 | 0.0000 | 0.6400 | 0.8000 |
| 2145.000 | 0.0000 | 0.8000 | 0.4800 | 0.0000 | 0.0000 | 2.0800 | 1.4400 | 0.0000 | 0.0000 | 1.1200 |
| 2148.750 | 0.0000 | 0.5600 | 1.1200 | 0.0000 | 0.0000 | 2.4000 | 1.9200 | 0.0000 | 0.0000 | 1.4400 |
| 2152.500 | 1.9200 | 1.1200 | 0.3200 | 0.0000 | 0.0000 | 0.0000 | 2.0800 | 0.0000 | 0.0000 | 0.3200 |
| 2156.250 | 0.4800 | 1.2800 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.9200 |
| 2160.000 | 1.4400 | 1.4400 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.9600 |
| 2203.750 | 1.1200 | 1.6000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4800 |
| 2207.500 | 0.0000 | 1.7600 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3200 | 0.0000 | 0.0000 | 1.4400 |
| 2211.250 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.8000 |
| 2215.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2218.750 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2222.500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2226.250 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2230.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2233.750 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.9200 |
| 2237.500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.1200 |
| 2241.250 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4800 |
| 2245.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 3.2000 |

TABLE II

## EXAMPLE OF PROGRAM OUTPUT IN ATTENUATION

RESULTS FOR STORM ON APRIL 1 1973

ATTENUATION AT A 20 DEGREE ELEVATION ANGLE IN DB

| TIME | GAUGE NO 1 | GAUGE NO 2 | GAUGE NO 3 | GAUGE NO 4 | GAUGE NO 5 | GAUGE NO 6 | GAUGE NO 7 | GAUGE NO 8 | GAUGE NO 9 | GAUGE NO 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2133.750 | 1.8417 | 9.1012 | 0.0000 | 32.4841 | 0.0000 | 17.4303 | 17.4303 | 0.0000 | 82.8784 | 6.5508 |
| 2137.500 | 6.5508 | 6.5508 | 0.0000 | 35.6304 | 0.0000 | 6.5508 | 6.5508 | 0.0000 | 6.5508 | 9.1326 |
| 2141.250 | 17.4303 | 9.1326 | 0.0000 | 0.0000 | 0.0000 | 32.4841 | 9.1326 | 0.0000 | 9.1326 | 11.8175 |
| 2145.000 | 0.0000 | 11.8175 | 6.5508 | 0.0000 | 0.0000 | 35.6304 | 23.3006 | 0.0000 | 0.0000 | 17.4303 |
| 2148.750 | 0.0000 | 14.5875 | 17.4303 | 0.0000 | 0.0000 | 42.0341 | 32.4841 | 0.0000 | 0.0000 | 23.3006 |
| 2152.500 | 32.4841 | 17.4303 | 4.1012 | 0.0000 | 0.0000 | 0.0000 | 35.6304 | 0.0000 | 0.0000 | 4.1012 |
| 2156.250 | 6.5508 | 20.3569 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 32.4841 |
| 2160.000 | 23.3006 | 23.3006 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 14.5875 |
| 2203.750 | 17.4303 | 20.3158 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 6.5508 |
| 2207.500 | 0.0000 | 29.3782 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 4.1012 | 0.0000 | 0.0000 | 23.3006 |
| 2211.250 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 11.8175 |
| 2215.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2218.750 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2222.500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2226.250 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2230.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2233.750 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 32.4841 |
| 2237.500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 17.4303 |
| 2241.250 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 6.5508 |
| 2245.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 58.6012 |

## TABLE III

### EXAMPLE OF PROGRAM OUTPUT IN TOTAL RAINFALL
### ACCUMULATION PER GAUGE

```
RAIN GAUGE NO.    1   C.42 INCHES

RAIN GAUGE NC.    2   0.65 INCHES

RAIN GAUGE NO.    3   0.12 INCHES

RAIN GAUGE NO.    4   C.25 INCHES

RAIN GAUGE NO.    5   C.00 INCHES

RAIN GAUGE NO.    6   C.5C INCHES

RAIN GAUGE NO.    7   C.5C INCHES

RAIN GAUGE NO.    8   0.00 INCHES

RAIN GAUGE NO.    9   0.34 INCHES

RAIN GAUGE NC.   10   1.07 INCHES
```

RAIN ACCUMULATIONS FOR EACH GAUGE

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## 4.0 STATISTICAL ANALYSIS

This section presents a plan for detailed analysis of the data from the ten rain gauges at WSTF. Because no data became available during the contract period, it was not possible to do any of the actual analysis. In all probability, it will be necessary to modify some of the procedures suggested below when the data becomes available. It is also probable that by examining the data (i.e., the computer printouts described in the previous section) other important parameters of the rainfall can be determined.

### 4.1 Diversity Improvement

One of the most important pieces of information to be learned from this experiment is the performance improvement to be gained by site diversity. For a single rain gauge a distribution can be made by plotting the number of hours a given rain rate is exceeded. The resulting curve would have the form of Figure 2. If the same procedure is followed for two gauges except that the gauge with the lowest value of rain rate (and/or attenuation) is used in any given time period, a curve such as that in Figure 3 can be drawn. This curve, marked "best of either gauge" represents the performance to be expected if two ground stations were in communication with one satellite and the station with the lower attenuation (rain rate) were used. It also assumes that the rain rate recorded at a particular ground location is valid throughout the entire path length. Methods for testing this assumption will be given below.

The above analysis can be carried further to three stations if it appears profitable when the data is available and examined. The technique would be identical except that the one station out of the three with the lowest rain rate would be used.
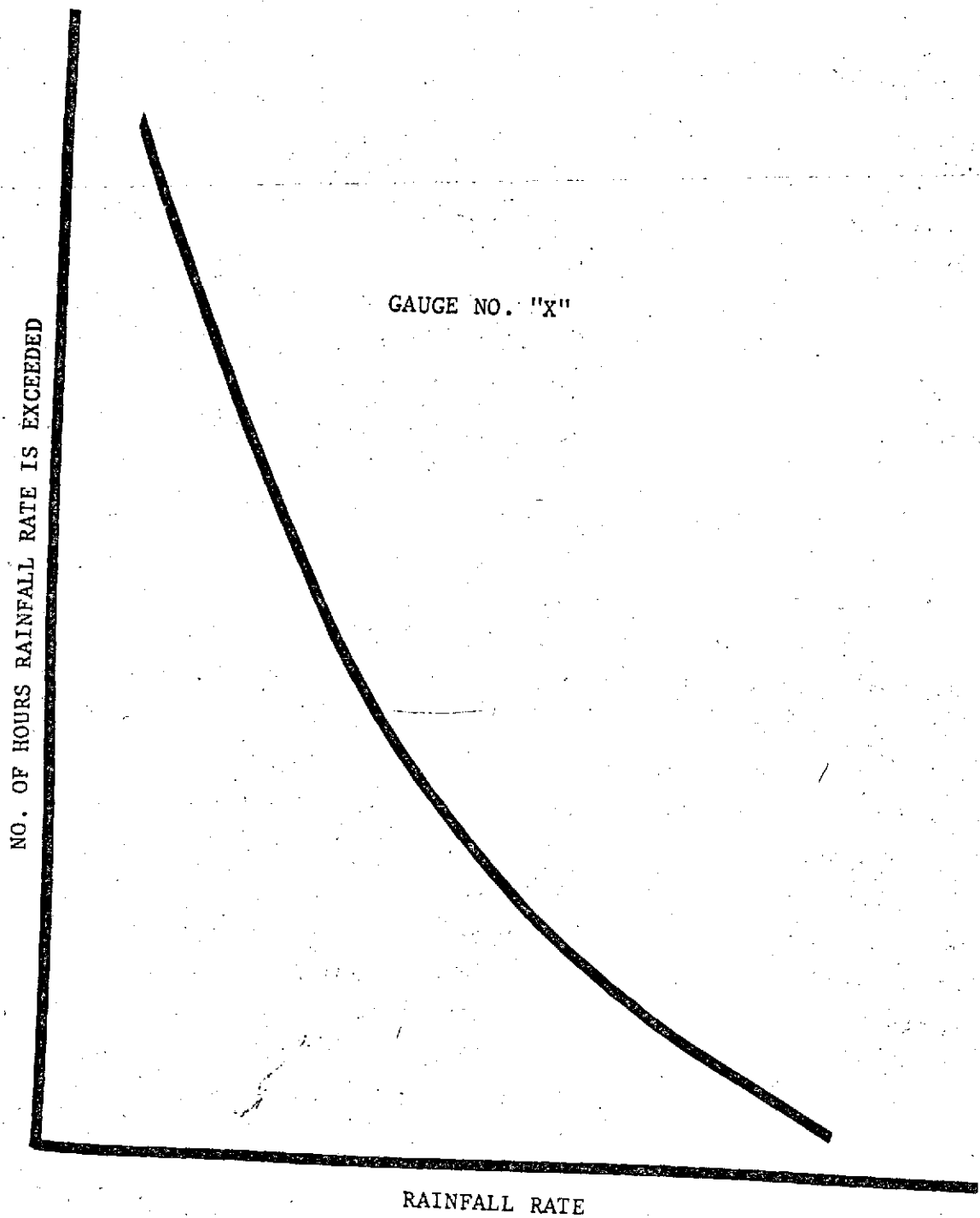
GAUGE NO. "X"

NO. OF HOURS RAINFALL RATE IS EXCEEDED

RAINFALL RATE

FIGURE 2
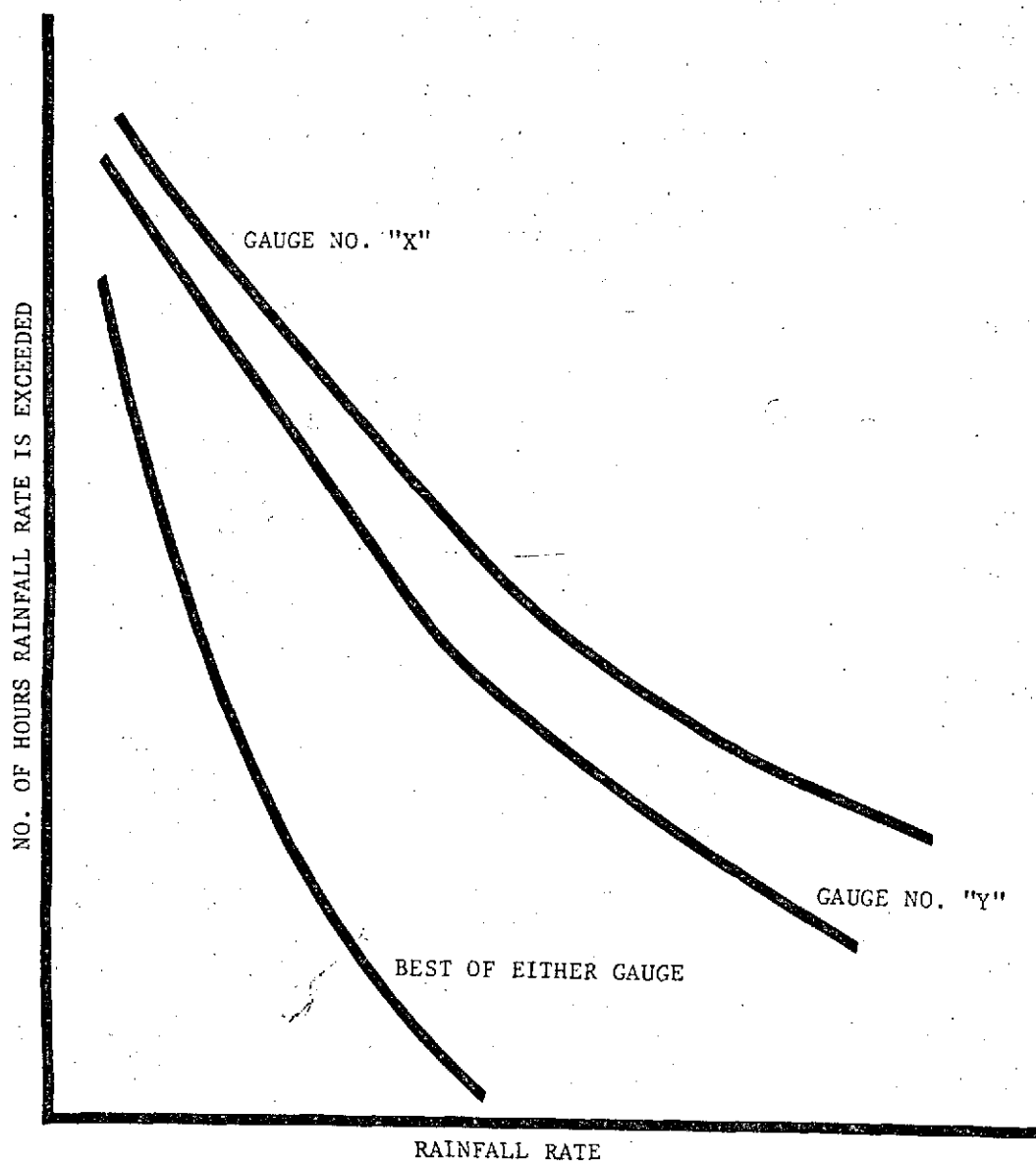EXAMPLE OF RAINFALL RATE DISTRIBUTION
FROM A SINGLE RAIN GAUGE

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FIGURE 3
EXAMPLE OF DIVERSITY IMPROVEMENT
FOR TWO RAIN GAUGES

Notice also that there are 45 combinations of the 10 rain gauges taken two at a time and therefore the output of the computer program described in the previous section should be scanned before performing these calculations. This should be done because, for example, it may be clear from inspection that there will be very little improvement or that the improvement is so good that it need not be plotted.

## 4.2 Correlation with the Radiometer

The four rain gauges that are under the path of the radiometer[1] should provide valuable information on the relationship between rainfall rate and attenuation and on the variation of rainfall rate over the path.

The rainfall rate attenuation model[2] that has been used has assumed that the attenuation is related to rainfall rate by

$$A \text{ (db)} = .039R^{1.155} \; P$$

where

$R$ = the rainfall rate in mm/hr

$P$ = the path length in km

$A$ = the attenuation in db

By comparing the attenuation as recorded by the radiometer with the attenuation calculated by using the above formula and the rainfall rate from the gauges (both individually and averaged over the path), an idea as to the validity of this formula for the WSTF can be obtained. This correlation should be performed in two different ways.

First, the attenuation can be compared over very short three-to-four minute intervals. Secondly, the attenuation distributions for a period of several months or more can be compared. It may turn out that even if the results do not agree over short intervals, they may

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agree over long time periods which is the most important consideration from a system design point of view. It has already been established that the rainfall rate attenuation model closely approximates the radiometer results for the excessive short duration rainfall statistics.[1]

. One of the necessities in modeling rainfall is to assume that the rainfall rate along the entire path is constant. The rain gauges at WSTF should prove useful in checking the validity of this assumption. Since there are two essential straight line paths in the layout of the rain gauges (see Figure 4 in Appendix I), this assumption can be checked for two different directions. In particular, the average rainfall along the path should be compared to each of the individual rain gauges to determine how much error there is when using this assumption. Of particular interest will be how the rainfall rate distribution of the average of all of the rain gauges compares to the rainfall rate distribution of the average of just those rain gauges over the path. These distributions should be obtained over a period of several months or more (i.e., 20 or more storms). If these distributions have good agreement, then the model assumption of constant rainfall rate should be valid even if this does not appear to be true on a short term basis.

4.3  Size, Shape and Motion of Storms

Due to the proximity of the mountains to the proposed NASA site at WSTF, it is very desirable to obtain an accurate idea of the size, shape and motion of the storms in this area. These results will help to determine which actual locations are best for the antenna locations.

The size of the storms are important because if it can be determined that a high percentage of the storms in this area are of limited extent, then it may be possible to locate the ground antennas far enough

apart that two antennas will not be affected simultaneously. The definition of size should be based on some acceptable low rain rate since rainfall rates which produce attenuation well below the power margin built into the TDRSS system will have no appreciable effect on the performance of the system.

A desirable method for displaying this information would be to develop contours on a map of regions corresponding to a rain rate that would just produce attenuation equal to the weather margin built into the system. It may turn out that for many storms this area will be so small as to not cause any severe problem.

In a similar manner the shape of the storms in this area may affect the placement of the antennas. For example, if the mountains cause certain regions of the storm to be narrower than others, it would be desirable to have the path from the ground antenna to the satellite pass through these narrow regions. There may be a tradeoff between siting the antenna based on the size of storms and siting the antenna based on the shape of storms. Until some actual data is available, however, it is difficult to predict the magnitude of these various effects.

When the size of the storm is determined, the shape of the storm will also be determined providing there is enough resolution (i.e., enough rain gauges spaced closely together.) After examining a number of storms it may be desirable to change the location of some of the rain gauges to obtain a better idea of the shape of storms in regions where it appears that there may be anomolies in the shape due to the mountains.

The motion of the storms can probably be best determined by making the contours described above at various times and observing the direction that the storms seem to be moving. It may also be possible to ascertain the motion of the storms by scanning the output of the computer program (Table I). If a repeatable pattern for the motion of storms, either on a yearly or seasonal basis, is determined, then this may influence where the sites are placed or how the system is operated during various times of the year.

It may be possible to write a computer program to automate some of these procedures after the data from a number of representative storms is available.

4.4  Simulation of Operational Strategies

One of the uses for the data which is gathered could be as inputs to a simulation model to study the operational characteristics of the system. For example, the three antenna sites could be simulated and various operational switching strategies could be evaluated. Some of the questions which might be answered are: is the best performance obtained by switching antennas when a critical rain rate is reached, or is it better to wait for the weather to clear? At what rain rate should antenna sites be switched? What time of day is it best to do the maintenance? Which antenna site should be the spare?

All of these questions can better be answered after the rainfall data is available.

APPENDIX I

DESCRIPTION AND DATA COLLECTION FOR WSTF RAIN GAUGE EXPERIMENT

This appendix has been published as a MITRE Working Paper, WP-10224, on 15 February 1973. It presents a plan for installing and servicing the rain gauges at WSTF. The locations of some of the rain gauges were changed slightly but at the present time their exact locations are not available.

1.0 PURPOSE

The only usable rain rate data currently available for estimating conditions in the White Sands area is that deduced from the U. S. Weather Bureau Excessive Short Duration Rainfall Statistics for El Paso, Texas, and Albuquerque, New Mexico. However, due to the proximity of the San Augustine Mountains to the WSTF, there could be considerable differences between the rainfall at WSTF and the rainfall which occurs at El Paso/Albuquerque. These differences could greatly affect the annual communications outages that have been calculated. Furthermore, there are no data available for determining the advantage of site diversity at a location such as WSTF. Thus, the installation and data collection of ten rain gauges, as described in this document, will be of paramount importance to:

(a) Obtain statistics for the WSTF area which will allow the determination of rain rate statistics, cell size, shape and velocity and consequently the expected communications outages and the value of separating ground antennas from about one to five miles; and

(b) Validate the individual components of the MITRE rainfall rate attenuation model (e.g., the relationship between the excessive short duration rainfall statistics and the true rainfall rate distribution).

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The results of this experiment could have a profound effect on the cost of the ground antenna system. For example, if it can be determined that there is a significant decrease in the power margin needed to obtain the desired availability by separating the antennas by four miles, then it may be possible to use smaller diameter antennas with a corresponding lower cost.

The remainder of this paper specifies the geography, installation techniques, and data collection procedures that should be followed to ensure success of the experiment.

## 2.0 GEOGRAPHICAL LAYOUT

The sketch in Figure 4 presents a suggested layout for the ten tipping bucket rain gauges. The figure is drawn roughly to scale. The rain gauges are laid out in a "cross" pattern which is oriented approximately north-south, in a line parallel with the general orientation of the St. Augustine Mountains and the three potential antenna sites. The separation among gauges is approximately one mile.

An attempt has been made to locate the rain gauges near existing facilities and roads so as to minimize the effort required to service them. The exceptions to this are gauges 3, 6, and 8 which are located in relatively flat country and should not be too difficult to service. Gauges 8, 9, and 10 are located under the 120° azimuth path from the radiometer to the TDRS. Gauge number 10 is located just off the WSMR Post Area access road at a distance of ten miles from the center line of the "cross". Information from this gauge should indicate differences between rainfall activity at the beginning and near the end of the path, the latter being across the St. Augustine Mountain Range.

This suggested layout may be modified slightly at the time of installation if it is determined that certain locations are undesirable because of inaccessibility, conflict with other WSTF activities,

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X OCCOTILLO RIDGE SITE

X LOVE RANCH SITE

------- NASA BOUNDARY

━━━━━ ROAD

——— AZIMUTH LINE

ELEVATION CONTOUR LINE

X        POTENTIAL ANTENNA SITE

⊙        RAIN GAUGE

□        RADIOMETER

SCALE

0        1        2        3 MILES

N

X QUARTZITE CANYON SITE

ST. AUGUSTINE MTNS.

ST. AUGUSTINE PEAK

TO HOLLOMAN AFB

NASA ACCESS ROAD

ORGAN

U.S. ROUTE 70

TO LAS CRUCES

ORGAN MTNS.

7000'
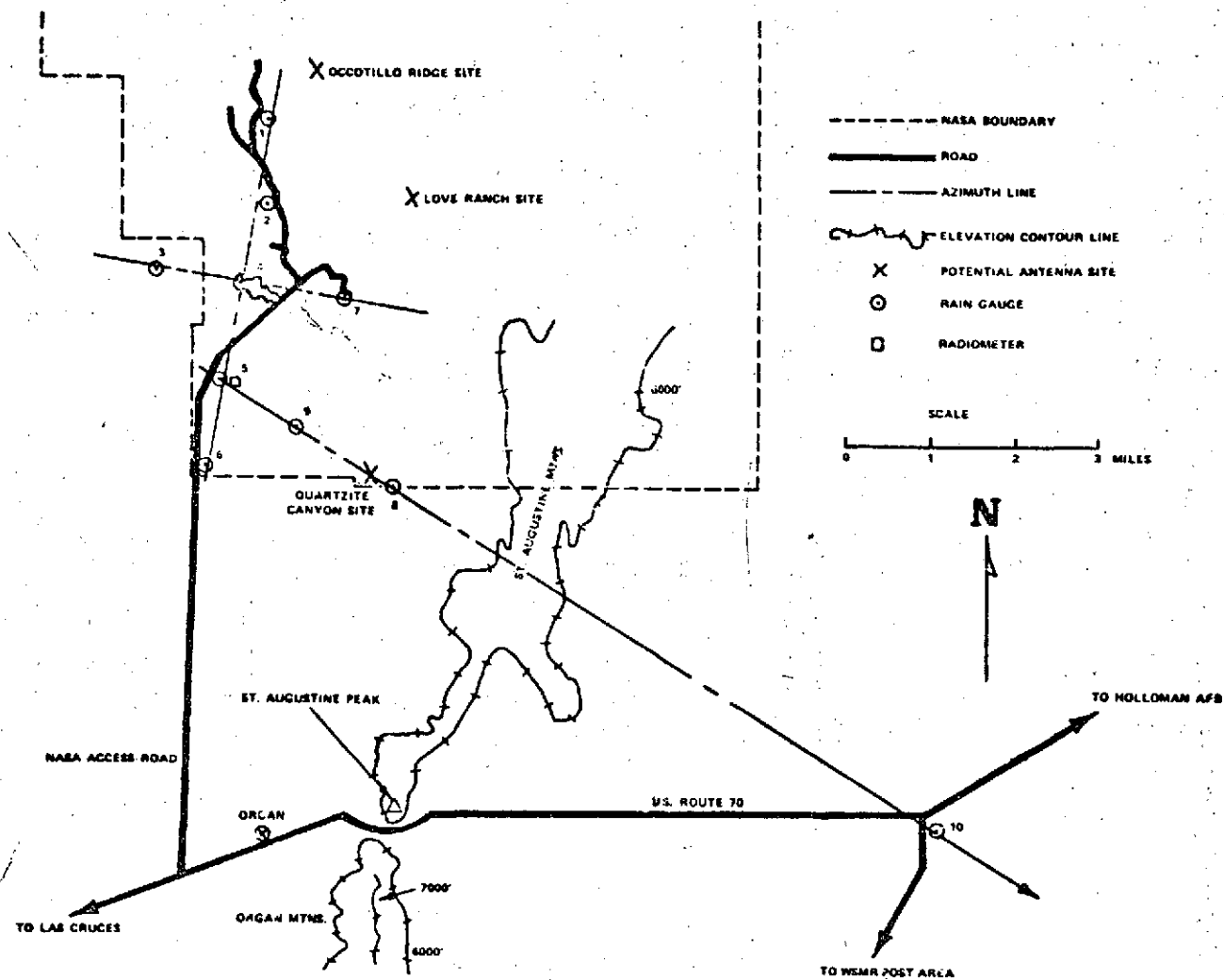
6000'

TO WSMR POST AREA

FIGURE 4

RAIN GAUGE EXPERIMENT LAYOUT

etc. The final locations should, however, be clearly indicated on a map of the area, drawn to scale.

## 3.0 EQUIPMENT INSTALLATION

The installation of the rain gauges should be done with care and according to the instruction supplied by the manufacturer. For example, the gauges should be on level ground (i.e., not on a slope or a roof) and the exposure at each site carefully considered. The gauges should be firmly fixed so they will not be blown over or tilted by the strongest winds. The surface on which they are located should not be hard and smooth in order to avoid water splashing into the gauges. The rim of the gauge should be horizontal and set with a level.

In a similar manner, the event recorder should be installed according to the specifications of the manufacturer. The recorder should be located far enough from the rain gauge so that rain will not splash from the recorder into the gauge.

## 4.0 DATA COLLECTION

The ultimate success of the experiment depends on the proper calibration and identification of the data. Thus, the following procedures should be followed when gathering the data:

(a) The paper tapes should be collected and replaced at least every twelve days since the capacity of the tape is only slightly more than this.

(b) The tape should be started such that a major division corresponds to the hour or the half-hour. Each inch should correspond to one-half hour. Time and data should be clearly marked on the tape.

(c) When the tape is removed the time should be marked exactly on the tape so that any speed inaccuracy can be detected. The tape should also be marked at the end as to the period of time covered and the identification number of the rain gauge.

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(d) In order to develop correlation between the gauges, the same time standard (e.g., watch) should be used in marking all tapes. Similarly, the time standard should be calibrated before changing tapes and the same calibration source (e.g., WWV) should be used every time.

(e) When changing tapes the rain gauges should be inspected for damage and any needed minor repairs should be performed and noted on the tape (e.g., sand cleaned out of tipping bucket).

(f) Batteries should be replaced when needed and ink supplies (if any) checked. Refer to manufacturer's instructions for recommended times.

(g) A daily log should be kept noting the date and approximate times when any of the above functions were performed. In addition, a weather observation should be noted each day (e.g., thunderstorm about 4 pm, no rain today, etc.).

APPENDIX II

COMPUTER PROGRAM LISTING

This Appendix presents a listing of the program which converts
the raw data from the chart recorders to tables of rainfall rate,
attenuation, and total accumulation (see Tables I, II and III in the
text). The listing contains detailed instruction for preparing the
data cards.

STMT LEVEL NEST
   1.                    MAIN    :PROCEDURE CPTICNS(MAIN);
                        /*

                              THIS PROGRAM TAKES THE INPUTS OF THE TEN RAIN GAUGES AT
                              THE NASA WHITE SANDS TEST FACILITY AND CONVERTS TO RAIN
                              RATE.

                              THE DATA ARE PREPARED AS FOLLOWS:

                                  FOR EACH STORM OR EVENT A CARD OF THE FOLLOWING FORM

                              *******

                        'APRIL'  1   1973   2133.75

                              *******

                              THIS CARD CONTAINS THE MONTH IN QUOTES,THE DAY,THE YEAR,
                              AND THE TIME WHICH THE FIRST SAMPLE STARTS. THIS TIME SHOULD
                              BE THE SAME FOR ALL TEN GAUGES AND SHOULD BE THE EARLIEST
                              TIME WHICH RAIN IS RECORDED FOR ANY GAUGE.

                              AFTER THIS CARD THERE SHOULD BE TEN SETS OF CATA CARDS, ONE
                              FOR EACH RAIN CAUGE. A TYPICAL SET WOULD LOOK LIKE THE
                              FOLLOWING:

                              *******

                        'GAUGE NO'  1   12   'POINTS'
                        1  3  7  0  C  12  3  9  7  C  C  6

                              *******

                              THE FIRST CARD IDENTIFIES THE GAUGE NUMBER AND THE NUMBER OF
                              POINTS TO BE ENTERED.
                              THE NEXT CARD CONTAINS THE DATA POINTS (DESCRIBED BELOW) IN
                              FREE FORMAT. REMEMBER,THERE ARE 10 SUCH SETS FOR EACH
                              STORM. IF A GAUGE RECIEVED NO RAIN,THEN ENTER  0  FOR  THE
                              NUMBER OF POINTS. ALL DATA SHOLD START AT THE TIME GIVEN ON
                              THE HEAD CARD BUT CAN END WHEN THERE IS NO MORE DATA.

                              THE DATA POINTS ARE AS FOLLOWS:

                                  COUNT THE NUMBER OF VERTICAL PEN MOVEMENTS PER ONE-EIGHTH
                                  INCH TIME INCREMENT (3.75 MINUTES) REMEMBERING THAT  THERE
                                  ARE 2 PEN MOVEMENTS PER VERTICAL DIVISION ON THE CHART.

                                  IF THERE ARE MORE THAN 300 STORMSOR MORE THAN 500 POINTS
                                  FOR ANY ONE RAIN GAUGE THAN THE DIMENSIONS IN THE
                                  DECLARE STATEMENTS SHOULD BE INCTEASED APPROPIATELY.

STMT LEVEL NEST

THE CURRENT DIMENSIONS WERE CHOSEN TO CONSERVE CORE USAGE.

```
                    */
  2      1               DECLARE  PCINT(10,500);
  3      1               DECLARE  RATE(10,500);
  4      1               DECLARE  X1 CHARACTER(10) VARYING;
  5      1               DECLARE  X2 CHARACTER(10) VARYING;
  6      1               DECLARE  MONTH(300) CHARACTER(10) VARYING;
  7      1               DECLARE  DAY(300);
  8      1               DECLARE  YEAR(300);
  9      1               DECLARE  TIMS(300);
 10      1               DECLARE  ATN(10,500);
 11      1               DECLARE  NPOINT(10);
 12      1               DECLARE  IGAUGE(10);
 13      1               DECLARE  SUM(10);

                  /* INITIAL ARRAYS  */

 14      1               POINT=0;
 15      1               RATE=0;
 16      1               DAY=0;
 17      1               YEAR=0;
 18      1               TIMS=0;
 19      1               ATN=0;
 20      1               IGAUGE=0;
 21      1               NPOINT=0;

              /* START LOOP ON STORMS   */

 22      1               DO NSTORM=1 TO 300;   /* CHANGE THIS IF NO. OF STORMS EXCEEDS*/

              /* READ HEAD CARD */

 23      1    1          ON ENDFILE (SYSIN) GO TO XOUT;
 25      1    1          GET LIST(MONTH(NSTORM),DAY(NSTORM),YEAR(NSTORM),TIMS(NSTORM));

              /* START LOOP ON EACH RAIN GAUGE */

 26      1    1          DO NGAUGE=1 TO 10;
 27      1    2          GET LIST(X1,IGAUGE(NGAUGE),NPOINT(NGAUGE),X2);

 28      1    2              DO N=1 TO NPOINT(NGAUGE);
 29      1    3              GET LIST(PCINT(IGAUGE(NGAUGE),N));
 30      1    3              END;

 31      1    2          END;

              /* ALL DATA FOR NSTORM NOW READ IN
```

STMT LEVEL NEST

```
                          /*CH CCNVEFT TO RAINRATE */

  32      1    1              DC NGAUGE=1 TC 10;

  33      1    2                  DO I=1 TO NPCINT(NGAUGE);
  34      1    3                  RATE(NGAUGE,I)=PCINT(NGAUGE,I)*0.16;
  35      1    3                  END;

  36      1    2              END;

                          /* THE WHOLE ARRAY CAN BE USED TO GET ATTENUATION AT A 20 DEGREE
                             ELEVATION ANGLE */

  37      1    1              ATN=.C39*9.35*((RATE*25.4)**1.155);

                          /* ACH PRINT RESULTS FCR THIS STCRM */

  38      1    1              PUT EDIT('RESULTS FUR STCRM ON ',MONTH(NSTORM),DAY(NSTORM),
                                  YEAR(NSTORM))(R(F1));
  39      1    1      F1    :FCRMAT(PAGE,SKIP(3),COLUMN(50),A,A,F(3),F(5));
  40      1    1              PUT EDIT('RAINFALL RATE IN INCHES PER HOUR')(R(F5));
  41      1    1      F5    :FORMAT(SKIP(2),CCLUMN(50),A);
  42      1    1              PUT EDIT('TIME',(10)' GAUGE NO ')(R(F2));
  43      1    1      F2    :FCRMAT(SKIP(3),X(3),A,X(8),10 A);
  44      1    1              PUT EDIT('1','2','3','4','5','6','7','E','9','10')(R(F3));
  45      1    1      F3    :FORMAT(SKIP,X(21),10(A,X(9)));

                          /* ACH PRINT CUT THE RAINFALL RATES */

  46      1    1              K=1;
  47      1    1              DC I=1 TC 10;
  48      1    2              IF NPCINT(I)>K THEN K=NPCINT(I);
  50      1    2              END;
  51      1    1              T=TIMS(NSTORM);
  52      1    1              CC I=1 TO K;
  53      1    2              PUT EDIT(T,'    ')(SKIP(2),X(3),F(8,3),A);
  54      1    2                  DC J=1 TO 10;
  55      1    3                  PUT EDIT(RATE(J,I))(F(10,4));
  56      1    3                  END;
  57      1    2              T=T+3.75;
  58      1    2              T2=T/100;
  59      1    2              T3=TRUNC(T2);
  60      1    2              TE=T2-T3;
  61      1    2              IF TE >= .60 THEN T=T+40;
  63      1    2              IF T >= 2400 THEN T=0;
  65      1    2              END;

                          /* ACH PRINT ATTENUATION TABLE */

  66      1    1              PUT EDIT('RESULTS FCR STORM ON ',MONTH(NSTORM),DAY(NSTORM),
```

STMT LEVEL NEST

```
                                       YEAR(NSTORM))(R(F1));
 67     1     1         PUT EDIT('ATTENUATION AT A 20 DEGREE ELEVATION ANGLE IN DB')
                              (R(F5));
 68     1     1         PUT EDIT('TIME',(10)' GAUGE NO ')(R(F2));
 69    \1     1         PUT EDIT('1','2','3','4','5','6','7','8','9','10')(R(F3));
 70     1.    1         T=TIMS(NSTORM);
 71     1     1         DO I=1 TO K;
 72     1     2         PUT EDIT(T,'        ')(SKIP(2),X(3),F(8,3),A);
 73     1     2              DO J=1 TO 10;
 74     1     3              PUT EDIT( ATN(J,I))(F(10,4));
 75     1     3              END;
 76     1     2         T=T+3.75;
 77     1     2         T2=T/100;
 78     1     2         T3=TRUNC(T2);
 79     1     2         TE=T2-T3;
 80     1     2         IF TE >= .60 THEN T=T+40;
 82     1     2         IF T >= 2400 THEN T=0;
 84     1     2         END;

               /* NOW DETERMINE RAIN ACCUMULATION */

 85     1     1         SUM=0;
 86     1     1         DO J=1 TO 10;
 87.    1     2              DO I=1 TO NPOINT(J);
 88     1     3              SUM(J)=SUM(J)+POINT(J,I);
 89     1     3              END;
 90     1     2         END;
 91     1     1         SUM=SUM*0.01;

               /* NOW PRINT RAINFALL ACCUMULATIONS */

 92     1     1         PUT EDIT('RAIN ACCUMULATIONS FOR EACH GAUGE')(PAGE,SKIP(3),
                              X(20),A);
 93     1     1         DO J=1 TO 10;
 94     1     2         PUT EDIT('RAIN GAUGE NO. ',J,SUM(J),' INCHES')(R(F4));
 95     1     2    F4   :FORMAT(SKIP(2),A,F(3),F(6,2),A);
 96     1     2         END;

               /* ALL DATA FOR THIS STORM  NOW PRINTED */

 97     1     1         POINT=0;
 98     1     1         RATE=0;
 99     1     1         END;
100     1               PUT EDIT('ARRAY DIMENSIONS MUST BE INCREASED TO PROCESS MORE ST
101     1         ORMS')(SKIP,A);STOP;
102     1         XOUT :STOP;
103     1               END MAIN;
```

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# LIST OF REFERENCES

1. Kalagher, R. J., _Analysis of the NASA WSTF Radiometer Experiment to Determine 16 GHz Attenuation Due to Rainfall_, MITRE Technical Report, 21 May 1973.

2. Burgess, J., R. Kalagher, and R. Welf, _Tracking and Data Relay Satellite System: Network Configuration Study_, MITRE Technical Report, MTR-6269, Vol. III, September 1972.

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